53/02

HSR Supersonic Laminar Flow Control

High-Speed Research Project

4.3 Aerodynamic Performance

4.3.4 Supersonic Laminar Flow Control
An Overview

NASA Langley Research Center

HSR CA Workshop/February 27, 1996

SLFC ITD:

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SLFC Mission Statement

Develop and validate technologies for Supersonic Laminar Flow Control (SLFC) and perform the SLFC aerodynamic design for the HSCT with an assessment of the net benefit and risks.

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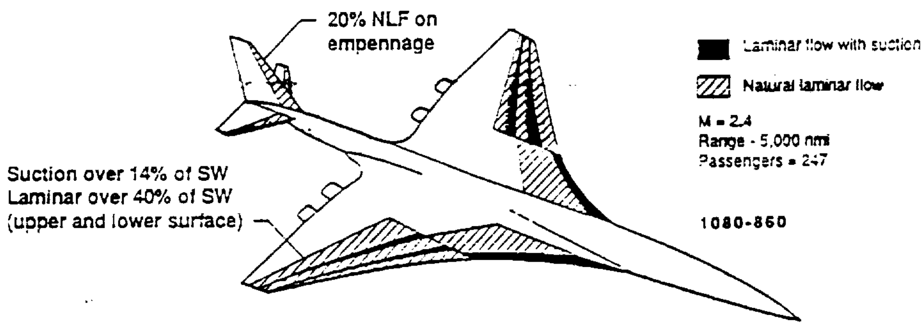
SLFC Benefits

HLFC Application to HSCT



Aerodynamic Benefit:	**8 to 10% Increase in Cruise L/D**
Implementation Penalties:	**Systems and Structural Weight Increment, Fuel Displacement, TSFC, Suction Air Momentum Drag**
Performance Benefits:	**ΔMTOW=-6 to -8%, ΔBlock Fuel=-10 to -12% ΔEngine Airflow=-8 to -12%**
Thermal Benefits:	**Reduced Skin Temperatures - Reduced Fuel Heating rate - Increased Materials Options**

Benefits would be larger for a heavier/longer-range configuration and for HLFC scheme with wall cooling

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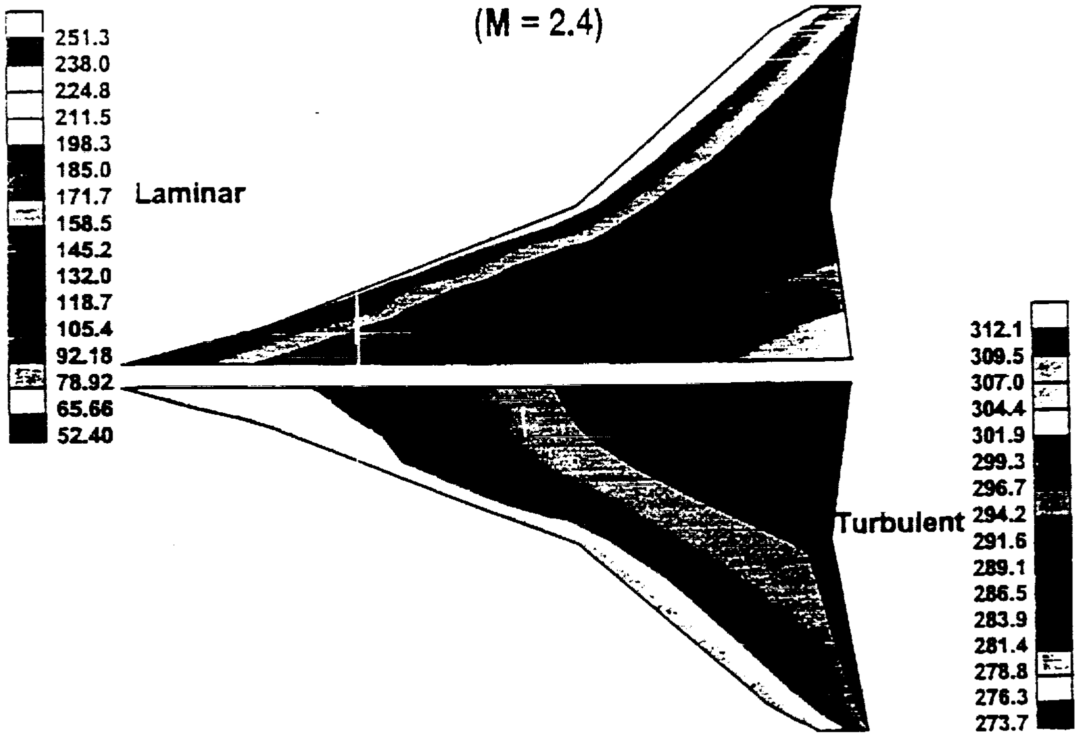
Benefits of SLFC

- **8% increase in cruise L/D (9.3=>10)**
- **11% reduction in fuel burn (390,000lbs=>347,100lbs)**
- **7% reduction in MTOW (740,000lbs=>688,200lbs)**
- **50-100 degree(F) reduction in local skin temperatures**

Laminar and Turbulent Surface Temperatures

(M = 2.4)



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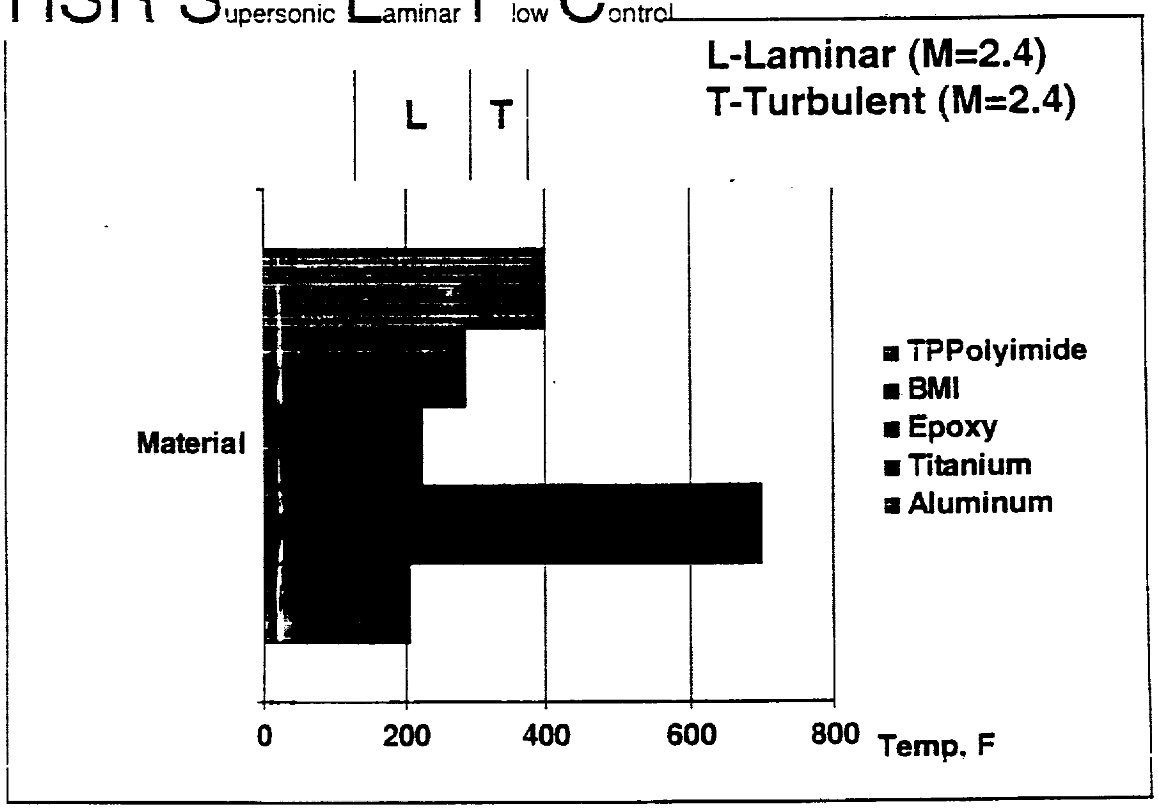

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SLFC Major Issues

- BL Suction - Where? How much?
- Impact on Inviscid Drag

- Weight of Suction System
- Compatible High Lift System
- Leading Edge Protection - Insects, Ice
- Complexity & Cost of Systems and Structure
- Durability & Maintainability

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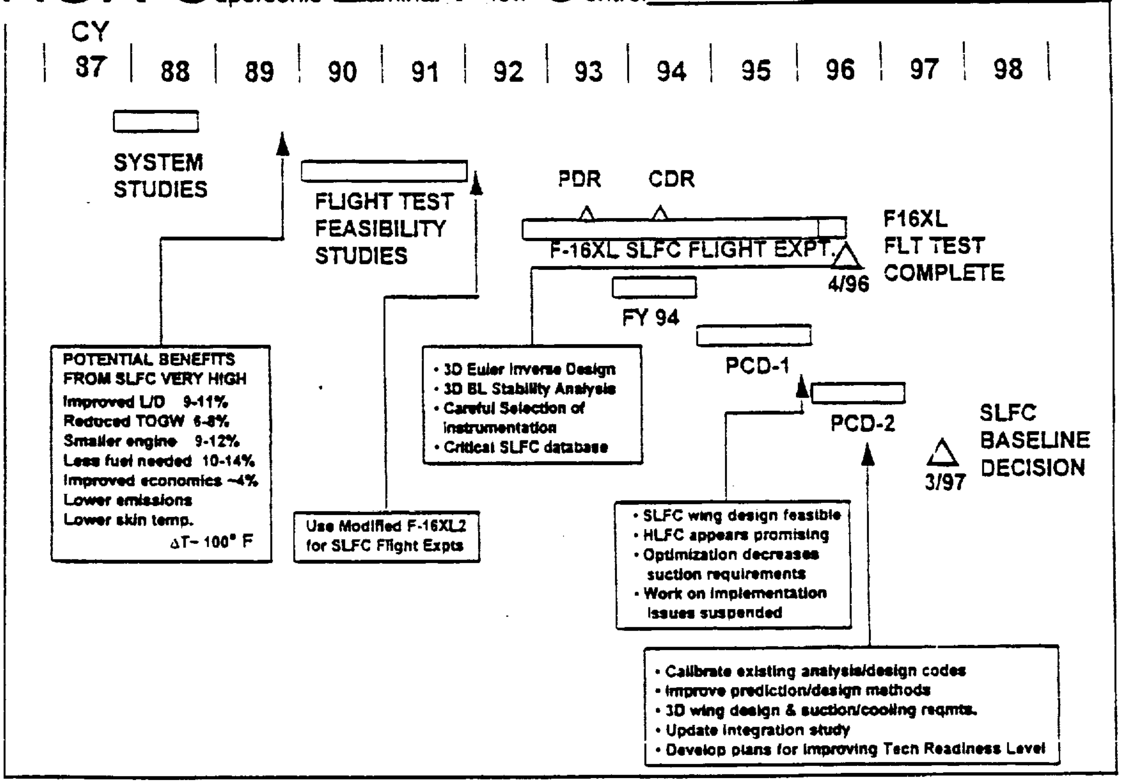
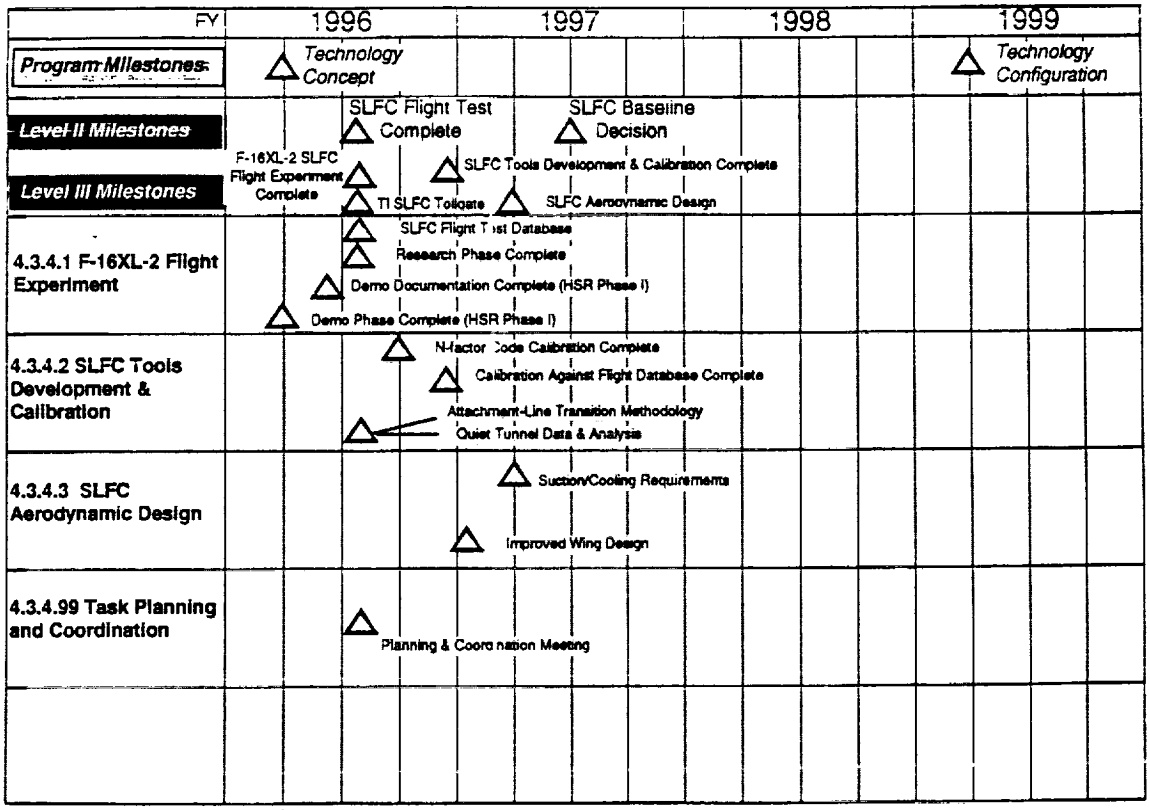


4.3 AERODYNAMIC PERFORMANCE
4.3.4 Supersonic Laminar Flow Control



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4.3.4.1 F-16XL-2 Flight Test
(Hardware Demonstration)

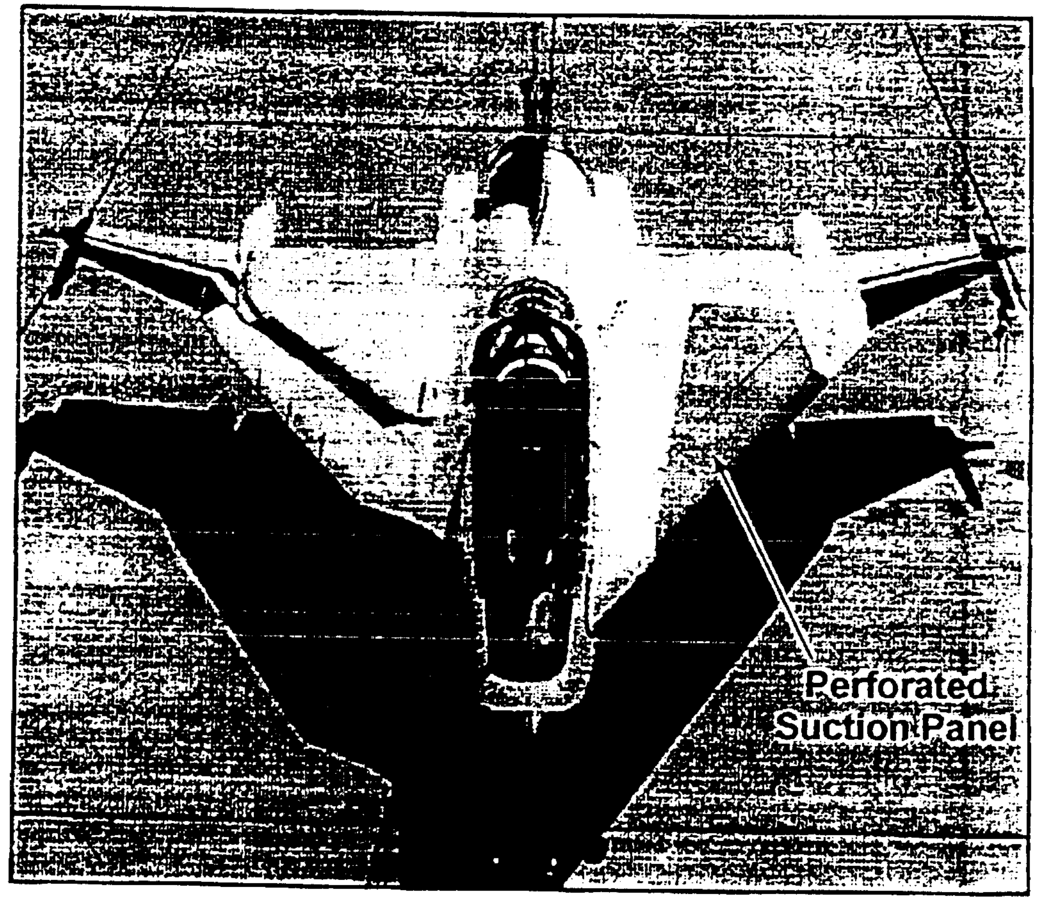
F-16XL-2 SUPERSONIC LAMINAR FLOW CONTROL EXPERIMENT

OBJECTIVES:

- Demonstrate achievement of laminar flow to 50-60% chord on a highly swept wing at supersonic speeds

- Obtain flight data for CFD code validation and development of design methodology

- Establish initial SLFC design criteria to provide a more realistic assessment of SLFC benefits for the HSCT



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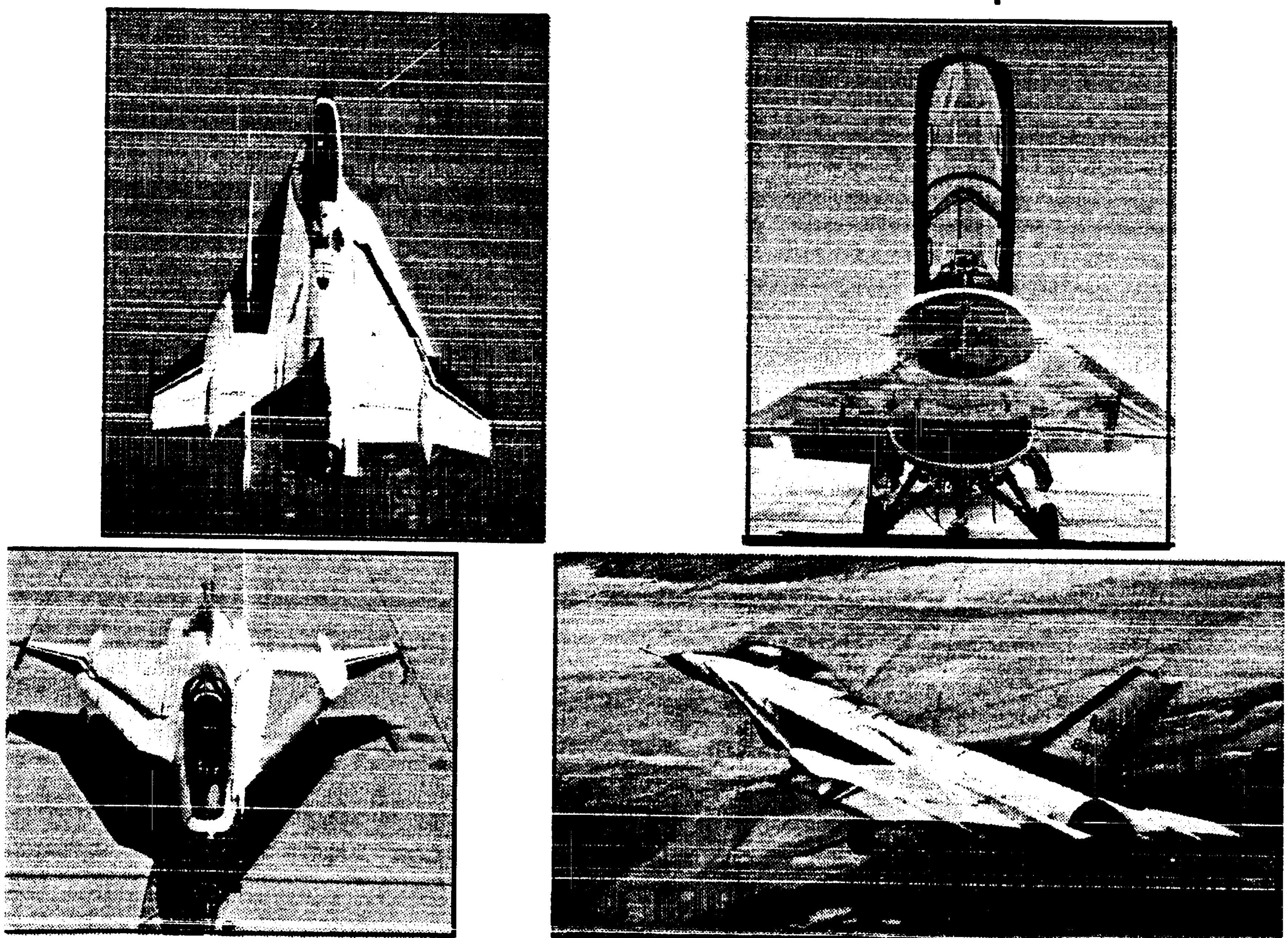
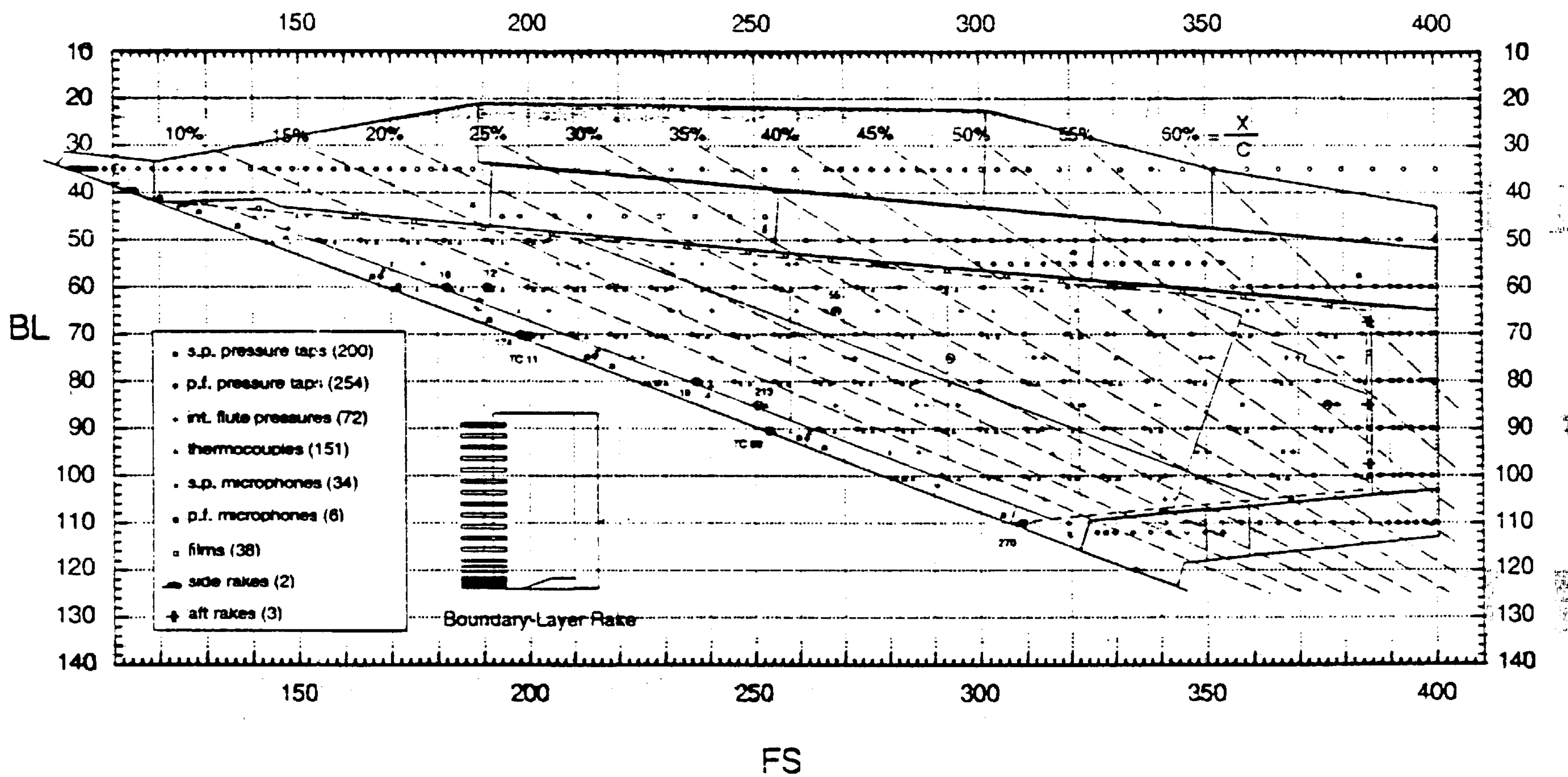
F-16XL Supersonic Laminar Flow Control Experiment



F-16XL2 SLFC WING INSTRUMENTATION



Notes: 1.) Circled instumentation did not pass BCAG Q/A.
2.) Only the two failed Suction Panel leading edge pressure taps shown (113 total in l.e.)

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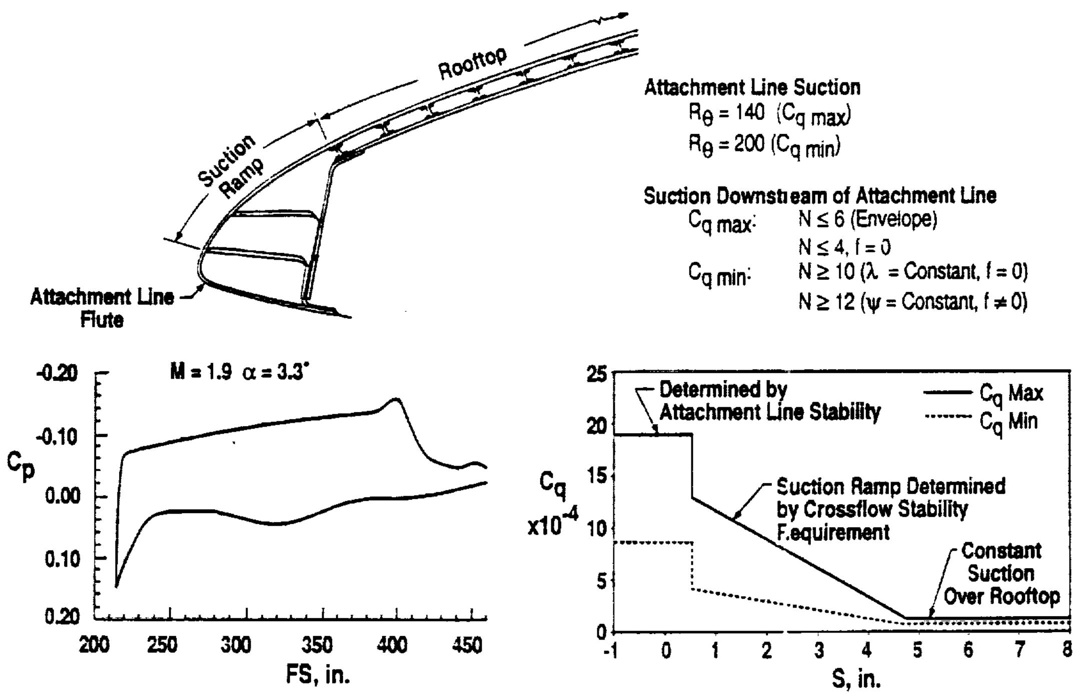
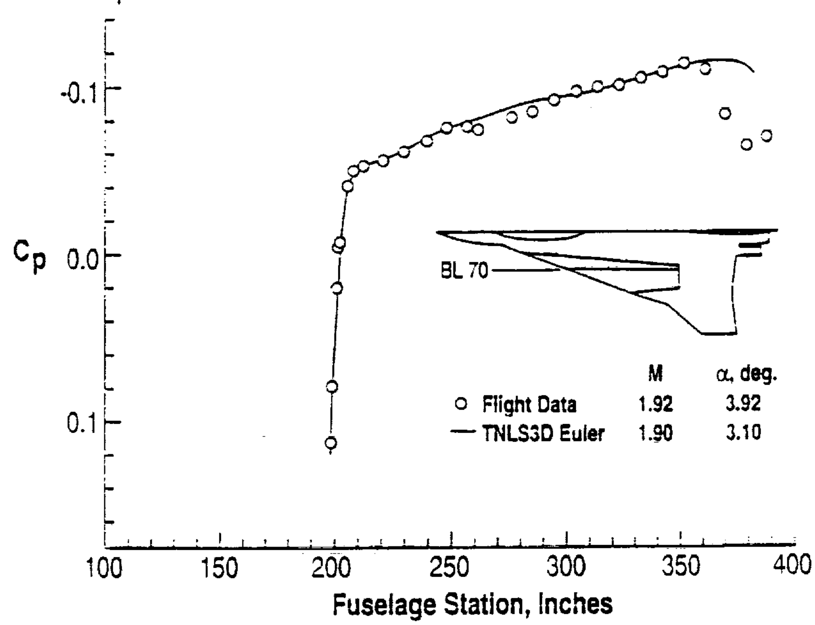
AERODYNAMIC AND SUCTION REQUIREMENTS



F-16XL-2 SLFC Flight Experiment

Comparison of Measured and Predicted Surface Pressures



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4.3.4.2 SLFC Tool Development

a. Tool calibration
b. Quiet tunnel database

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Tool Calibration from F-16XL database

Flight Data: Cp, Tw, Suction flute meas.

Douglas Approach

FT2SA

Produces smooth CP, CQ data on a fine surface grid

INTWNG-SE (surface Euler)

Edge velocities for BL3D by solving the surf. Euler equations based on the input CP and attachment line location

BL3D

EMALIK3D → Correlation with measurement of transition location

Boeing Approach

BOEING POST-PROCESSOR

similar to FT2SA but no smooth interpolation to fine grid

CDISC+EULER

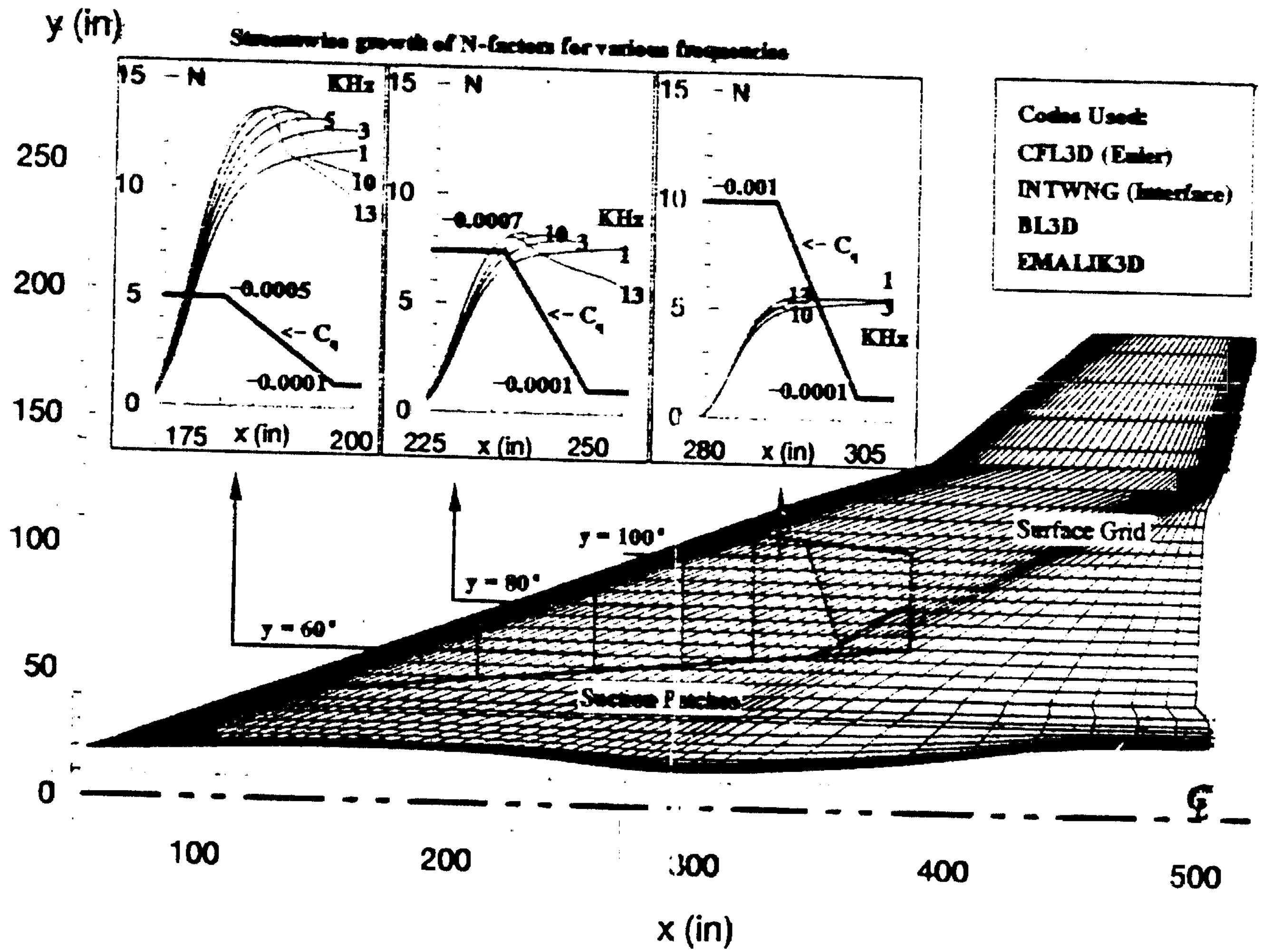
Inverse design of surface to match the input CP at measured locations with Euler solution at these locations

INTWNG-INT or BL3D interface

Produces edge velocities for BL3D by interpolation of Euler velocities and location of attachment line using Euler velocities

Predicted N-factors on the F16XL Suction Glove at Design Point

(assuming a representative suction distribution (C_q) achieved by the suction patches)



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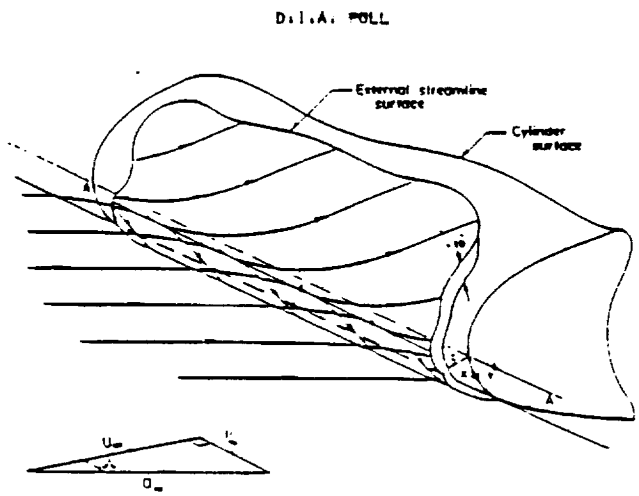
Sketch of Attachment-Line Region



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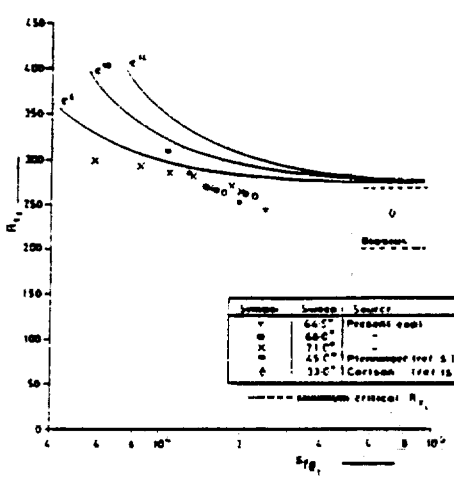
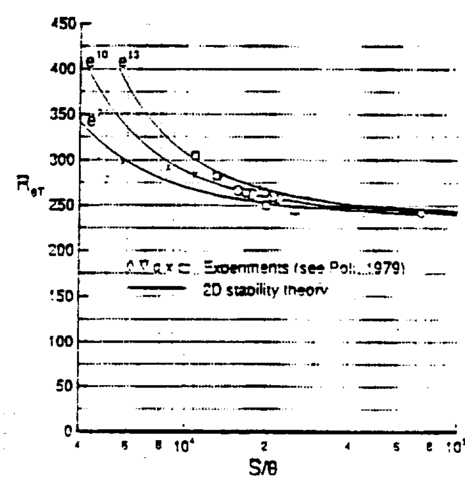
N-factor Correlation

Parallel Method **2D-Eigenvalue Approach**





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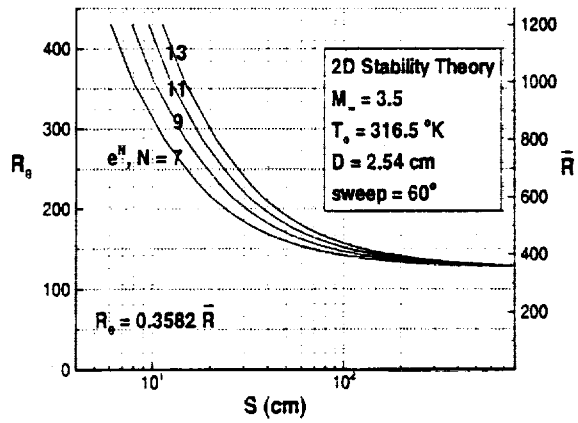
Constant N-valued Curves for Transition Correlation



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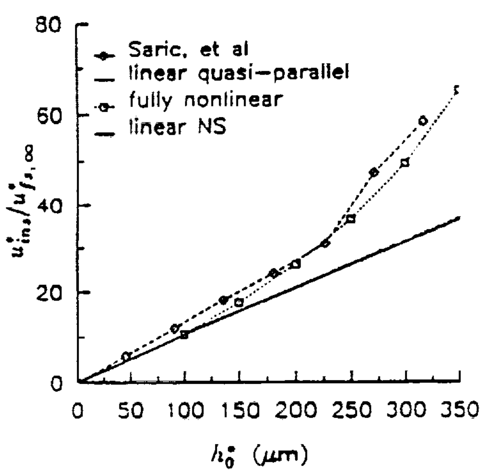
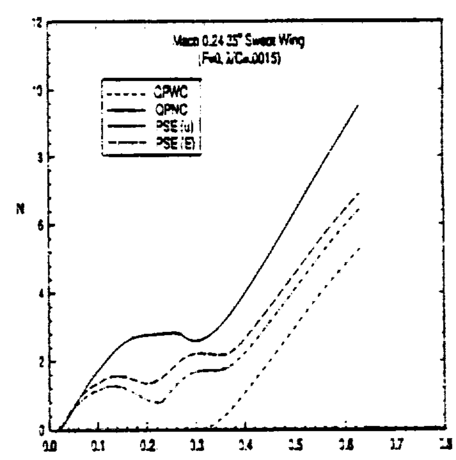
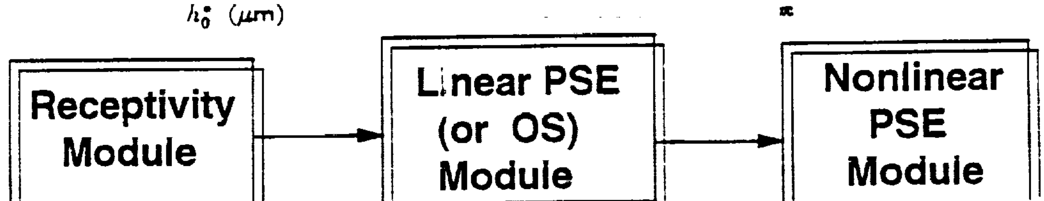
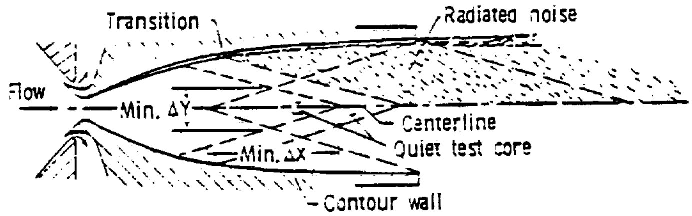
Embryonic "Next generation" tools

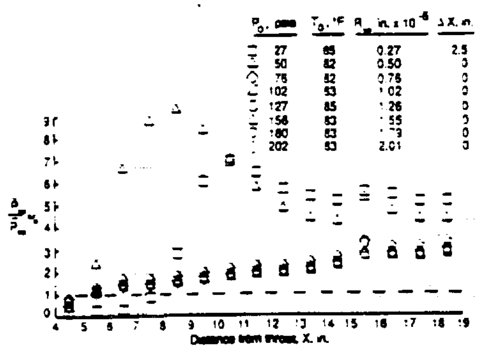




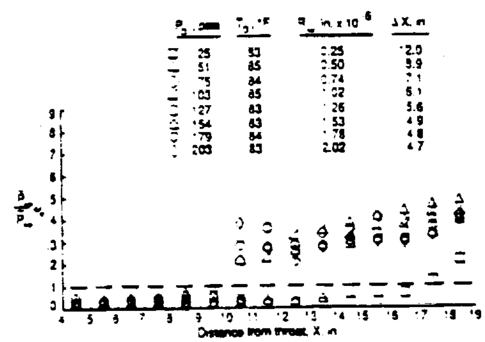


Significance of Quiet Tunnels





(c) Bleed valve closed, Y = 0.



(a) Bleed valve open, Y = 0.

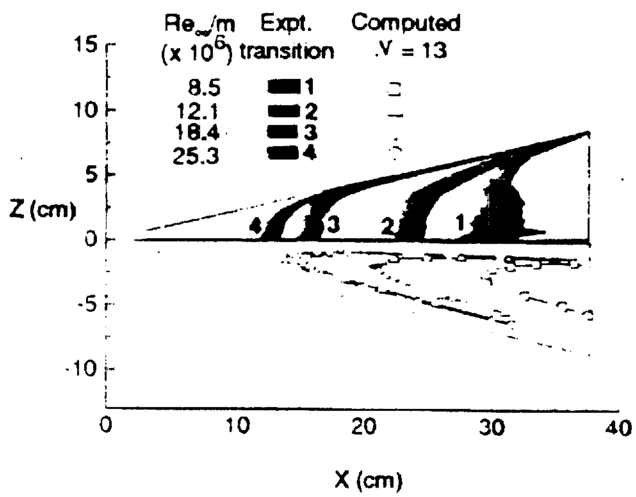


Fig. 1 Transition location correlates well with N=13 over a wide range of unit Reynolds numbers.

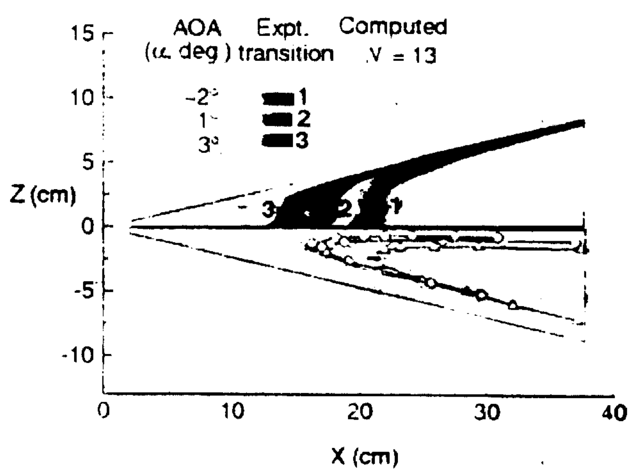


Fig. 2 Transition location also correlates well with N=13 over a wide range of angles of attack.

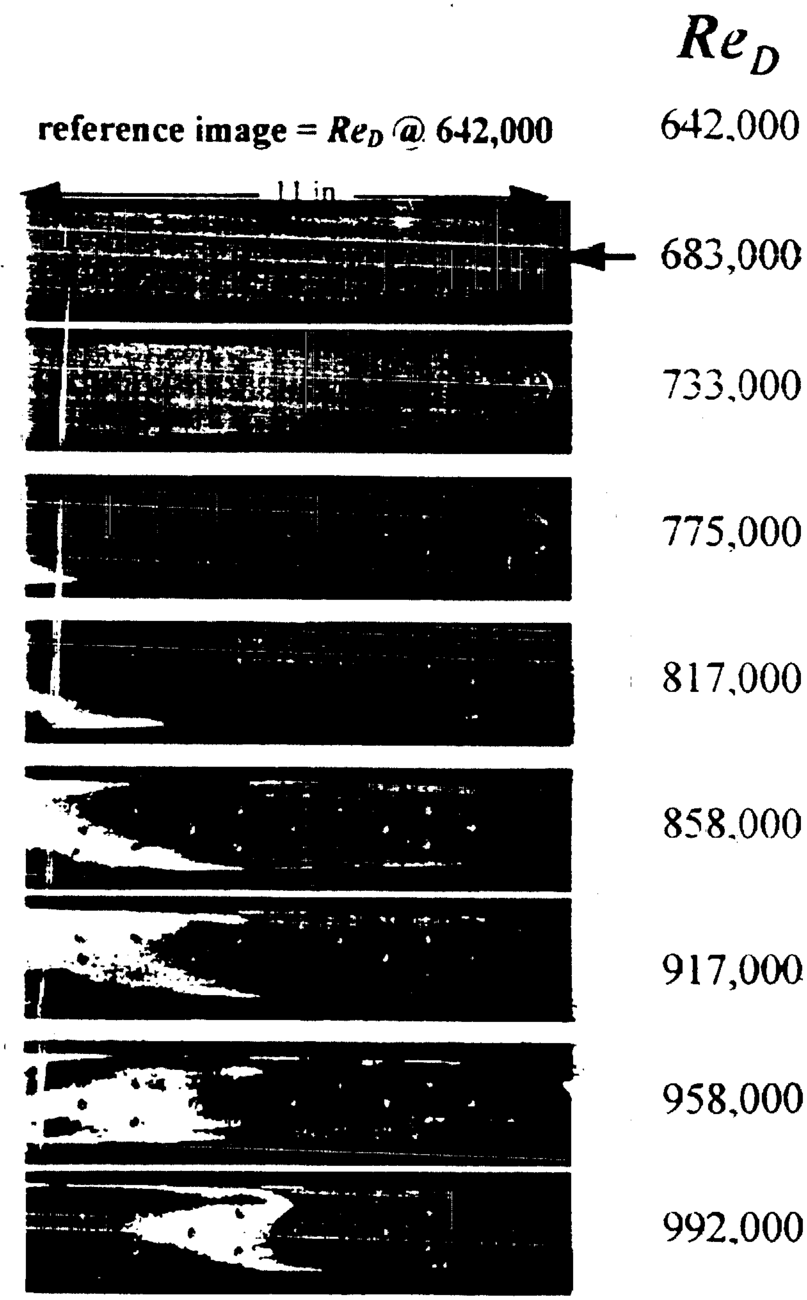


Fig. 3 Transition location on 1 in. diam. 76 deg. swept-cylinder model vs. Re_D using TSP.

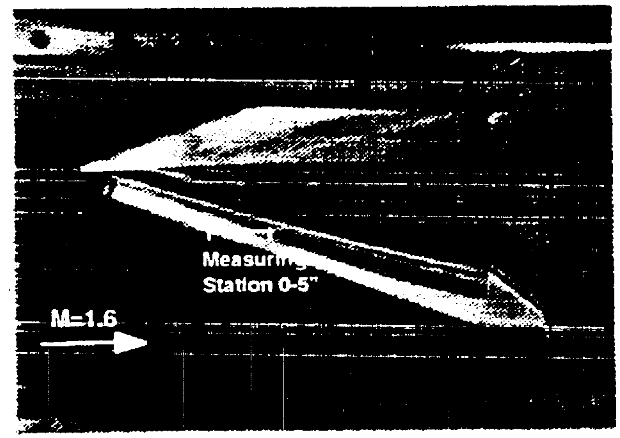
Swept Wing Model Test in FML Laminar Flow Supersonic Wind Tunnel

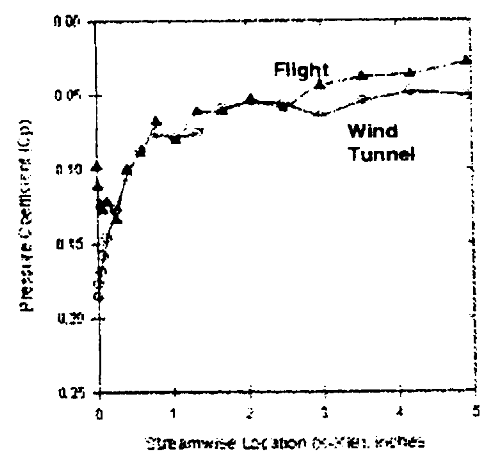
RESEARCH OBJECTIVE: Obtain pressure and transition data on a full-size segment of the F-16XL passive glove for comparison with flight data and CFD validation

APPROACH: The M1.6 Quiet Tunnel was designed to operate in the same Reynolds number range as the F-16XL laminar flow test vehicle. A pressure model was tested in FY95. The next entry will employ thermally sensitive paint to determine transition location. Transition is expected to occur due to attachment line contamination and by crossflow instability mechanisms.

APPLICATION: These tests are in support of laminar flow control for the next generation supersonic transport.

STATUS/PLANS: Pressures were measured during the first entry. A comparison with flight data is shown here (angles of attack were adjusted for best match). The next entry, expected in Feb-Mar. 1996, will investigate transition in the leading edge region.





4.3.4.3 SLFC Aerodynamic Design

- Design wing contour
- Suction & cooling requirements
- Step/gap/waviness requirements
- Compute skin friction reductions
- Calculate BLC suction requirements

Summary

SLFC Impact on HSCT:

Aerodynamic & Economic Benefits
- Drag reduction, Increased L/D,
- Reduced MTOW, Lower skin temps, etc.

PCD 2:

4.3.4.1 F-16XL-2 SLFC Flight Experiment
4.3.4.2 SLFC Design Tool Methodology
4.3.4.3 SLFC Aerodynamic Design